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AEROSPACE FINAL DESIGN REPORT

1991-92

NASA/USRA Design Project: Extended Mission/Lunar Rover

FAMU/FSU College of Engineering
Aerospace Design Program
Executive Summary

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1. INTRODUCTION

A key component in ensuring America's status as a leader in the global community is its active pursuit of Space Exploration. On the twentieth anniversary of Apollo 11 President Bush challenged our nation to permanently place a man on the moon and eventually conduct human exploration of Mars in the twenty-first century. The name for this challenge is America's Space Exploration Initiative (SEI) and the students of the FAMU/FSU College of Engineering hope to make a significant contribution to the SEI with their participation in the NASA/USRA Advanced Design Program.

The design project selected to be undertaken by the 1991/92 Aerospace Design Group was that of conceptually designing an Extended Mission Rover for use on the Lunar Surface. This vehicle would serve the function as a mobile base of sorts, and be able to provide future astronauts with a mobile "shirt-sleeve" self-sufficient living and working environment. Some of the proposed missions would be planetary surface exploration, construction and maintenance, hardware set-up and in-situ resource experimentation. The need for this type of vehicle has already been declared in the Stafford Group's report on the future of America's Space Program, entitled "America at the Threshold: America's Space Exploration Initiative". In the four architectures described within the report, the concept of a pressurized vehicle occurred multiple times. The approximate time frame that this vehicle would be put into use is 2010-2030.

1.1 Project Management and Organization

The overall organization of the 1991/92 Senior Aerospace Design class was conducted in a matrix management fashion. All of the students involved in the project were assigned to a Design Group and a Management group. By doing this it provided the students with a true feeling for how projects are organized in the industrial sector. The class consisted of seven mechanical engineering students and nine electrical engineering students. Due to the diverse make-up of the class, students were often involved in interdisciplinary tasks in the project. The overall organization of the class can be seen in Fig. 1.1. The upper level of project management consisted of a NASA/USRA interface along with a team of three faculty advisors. The class met twice a week, one day being reserved for guest lecturers on various aerospace related topics and the other day being reserved for work on the design project. At the class level a project manager was selected by the Faculty Board of Advisors through an interview process held at the end of the Spring 1991 semester. At the onset of the Fall 1991 semester a Deputy Project Manager was assigned. The function of the Deputy P.M. was to assist the P.M. in various organizational and interface duties. Also an Executive Systems Engineer was appointed at the start of the project. The main function of the Executive Systems Engineer was to oversee and predict possible integration conflicts between the design groups.

List of Student Participants

- Manh Chung: Reference Control, S.D.&I., MRWG
- Ken Clarke: Report Integration, S.D.&I., MRWG
- Kevin Frankle: Reference Control, S.D.&I.
- Anthony Halecki: Project Manager, S.D.&I*.
- Fariba Kassemkhani: Report Integration, Avionics
- John Kuhlhoff: Report Integration, Thermal/Fluid*, MRWG
- Josh Lenzini: Reference Control, Power Generation*
- David Lobdell: Project Control, S.D.&I., MRWG
- Sam Morgan: Visual Display, Fluids
- Robert Nock: Project Control, S.D.&I., MRWG
- Sabash Panigsahi: Visual Display, S.D.&I.
- Cynthia Robbins: Report Integration, S.D.&I.
- Mark Russell: Visual Display, S.D.&I.
- Rowi Shah: Visual Display, Avionics*
- Gail Wallace: Chief Systems Engineer, Project Control*, Thermal/Fluid
- Russell Willis: Report Integration*, Power Generation, MRWG
- * - Team leader.

Figure 1.1. Class organization.

The management teams organized for this project were the following: Project Control, Report Integration, Visual Display and Reference Control. The duties of the Project Control team included publication and distribution Bof weekly progress reports and agendas, overall project scheduling, requisitioning of needed supplies and equipment, and financial bookkeeping. The duties of the Report Integration team included the establishment of the format and outline of the final and midterm reports, mandating the acceptable graphics formats and layouts to be used in the report, and management and control of the Aerospace Design Account on the College of Engineering's VAX mainframe. The duties of the Visual Display team included the selection of the type of model to be displayed at the Summer USRA conference (multi-media or physical), production of any necessary visual display aides needed for the intermediary and final design reviews, and production of any necessary artwork for the report. The duties of the Reference Control team included upkeep and management of the Aerospace Reference Library, procurement of any additional necessary reference material, and interfacing with industry contacts.

The design teams organized for this project were the following: System Design and Integration, Avionics, Power Generation, and Thermal/Fluid. The duties of the System Design and Integration team included the design of the vehicle shell and supporting structures, selection/design of wheels and suspension system, identification of necessary redundant and emergency subsystems, logistics planning and support, basic maintanence scheduling, design/selection of air/man-lock, interior vehicle layout and supporting CAD drawings, and mass and volume budgeting. The duties of the Avionics team included design/selection of the necessary guidance and navigation systems, communications system,data acquisition and storage systems, design of necessary workstations and data management, and exterior environment imaging systems. The duties of the Power Generation team included selection and sizing of the appropriate fuel cell/system for vehicle support and locomotion, radiation shielding, and internal environmental control systems. The duties of the Thermal/Fluid Group included design/selection of proper fluid storage devices, critical fluid estimates and budgeting, pumping systems, hydraulics, fire suppression systems, and design/selection of the life-support and waste management systems.

2. MISSION STATEMENT AND REQUIREMENTS

The purpose of the design for an extended mission rover would be to provide transportation, shelter and working quarters for a crew of four on long duration lunar surface missions. To effectively fulfill this purpose a stand-alone temporary requirements group was formed. This group researched the proposed requirements submitted and suggested by the entire design class at a preliminary round-table meeting. By researching existing technologies and forecasts of available future technologies, the Mission Requirements Working Group reformulated the proposed requirements and restrictions into a collaboration of viable expectations. The preliminary mission requirements, as defined by the Mission Requirements Working Group, (MRWG) are as follows:

- Mission Distance: 1000 km round trip
- Mission Duration: 28 Earth Days (1 Lunar Day)
- Support Crew and Cargo (Oxygen, food, water, climate)
- Maximum Crew Size: 4
- Self-sufficient environment
- Maintain interior environment during egress
- Transport various experimental apparatus
- Possess robotic data sample/data collection capability
- Collect/analyze/store data
- Communication capability with base and earth
- Provide shielding from environmental elements
- Internal navigational support
- Unmanned capability
- Possess path-clearing abilities
- Travel over rough terrain (45° head-on, 20° traverse)
- Provide redundant systems

- Easily maintained

The list of requirements formulated by the MRWG were deemed acceptable and realistic by the entire Aerospace Design Class, and were used as the basis upon which to begin the conceptual design of the vehicle. Further justification for the acceptance of the crew size and total traverse distance was found in the Pressurized Manned Rover Requirements for long traverse vehicles. By keeping the expected traverse distance under 3000 km for a time period of approximately one month the size of the fuel cell tankage was kept small enough so that it did not become detrimental to the accomplishment of the stated mission objectives. The option of reformulation of the requirements was left open, with the stipulation of the approval of the project manger and chief systems engineer.

2.1 Mission Scenarios

The multi-purpose nature of the vehicle design makes it flexible enough for use in many applications. One such application would be that of extensive surface exploration. Although the lunar surface can be mapped with an orbiting satellite imaging system, the resolution of detail available from existing systems leaves something to be desired. By being able to venture great distances from the base, the vehicle allows firsthand observation and assessment of the terrain within a 500 km radius of the base. Extensive geological experimentation of sites located a great distance from the base could also be accomplished by utilization of the vehicle. Lengthy analysis and assessment of possible valuable mineral deposits could be conducted while the astronauts were habitating the vehicle. Also, set-up of such sensitive hardware as space radio telescopes could be done at a great enough distance from the permanent base's lander site so as not to cause interference from vibrations caused by the lander's engines. The capability of the vehicle to allow the realization of such scenarios as the aforementioned justifies the need for its design and eventual production. A side view of the vehicle can be seen in Fig. 2.1.

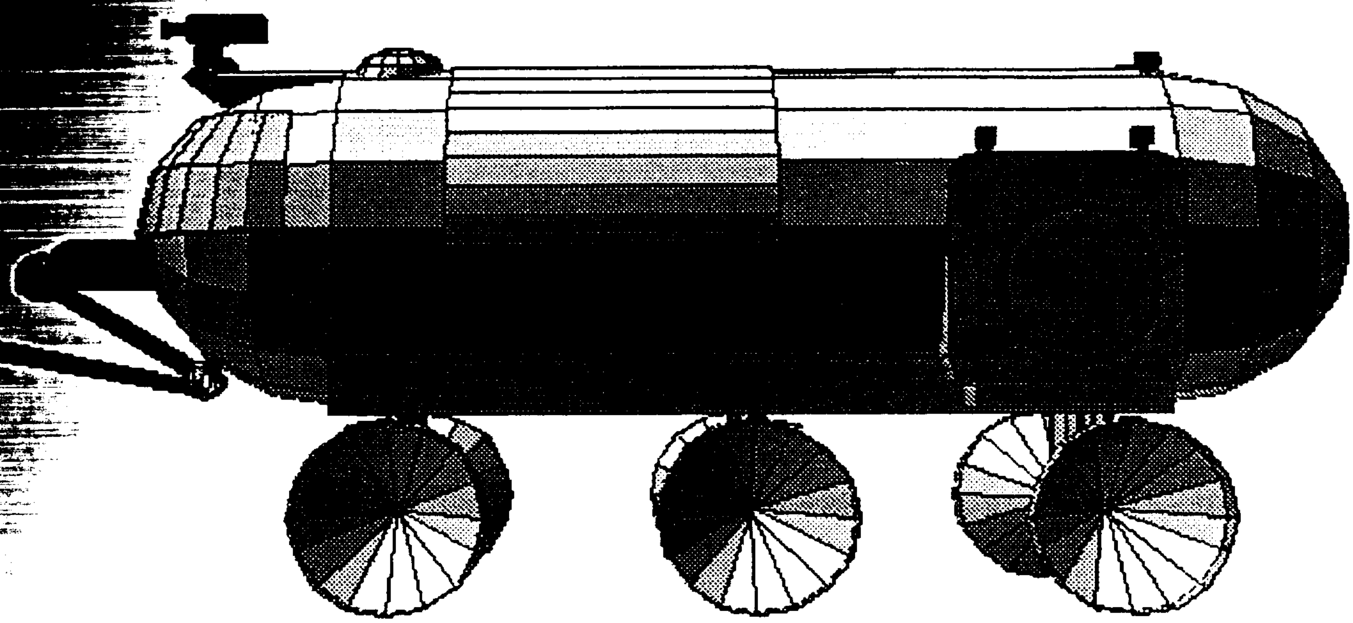

Figure 2.1. Side view of vehicle.

3. SYSTEM DESIGN AND INTEGRATION

3.1 Transportability

The design of the EMR was based upon the forecast of future technologies consistent with those included within available references. Rough calculations were also carried out to ensure compatibility with these predictions. Rather than trying to carry out detailed calculations of the transportation system, the approach was to ensure that the mass and size of the EMR did not exceed the limitations predicted by the available references.

From the report released by Boeing Defense and Space Group, Advanced Civil Space Systems in Huntsville, Alabama a launch vehicle and lander system was found that would easily accomodate the EMR. The estimated payload delivered to the lunar surface was 45mt. This was based on the concept of delivering a fully integrated habitat to the lunar surface. This would fit into Boeing's LTV tandem stage expendable mode using the Direct, Lunar Orbit Rendezvous (LOR) high-thrust profile. The launch vehicle proposed by Boeing was in the range of 100-400mt with a payload shroud of 10m diameter by 30m length. The suggested way to carry the cargo would be to hang it on the underside of the Lander. If the payload is to be underslung on the lander, some deployment or assembly may be needed on orbit if the diameter limit of the launch vehicle is less than 10m. The reason for proposing the idea of an underslung cargo is the inherent ease of unloading once the vehicle has reached the lunar surface.

3.2 Suspension

The rough terrain of the Lunar surface represents great difficulties for the locomotion system of a ground based vehicle. Mobility requirements for a lunar based vehicle are very diverse. Mission requirements vary greatly and the environment of locomotion may be literally anywhere on the moon. To best meet these diverse needs, all practical mobility concepts were examined. The different types of mobility concepts examined were: Tracked vehicles, walkers, and wheels.

Wheels will be the preferred mobility option for many missions. Wheels are mechanically efficient, they can be designed into lightweight systems, and can be built with excellent reliability. One problem with wheels in terrestrial all-terrain applications is that they tend to have a small footprint. In the reduced gravity field of the moon, having a large ground contact area is not required.

The ELV will make use of six cone-shaped carbon graphite wheels with a suitable diameter of 72 inches and a thickness of 0.5 inches. The tread width will be 20 inches which will give maximum traction which will help prevent slippage on the lunar surface. This wheel will give an estimated minimum ground clearance of 36 inches. The overall weight for six cone wheels will be approximately 624 kg.

To accomplish the vehicle mission, the suspension system must meet the following requirements: 1) It must ensure height mobility under conditions of rough terrain on the lunar surface, and loosely cohesive soil with low bearing strengths and a coefficient of resistance to motion (f of 0.6). 2) Overcome elevations of up to 25 degrees. 3) Ensure reliable motion on the lunar surface despite various obstacles: groups of rocks, scarps, and counter-scarps, fissures and craters. 4) Ensure a highly reliable operation of all systems without need for repair within the required service life, the design of the suspension must be of definite geometric size with a minimum weight in keeping with the requirements of the space rocket capacity. See Fig. 3.1 for details regarding the primary and secondary suspension system.

3.3 Radiation Shielding

The problem of providing enough radiation shielding for the crew of the EMR was approached from a very conservative point of view. It has been suggested that a spacecraft with shielding equivalent to 5 gm/cm^2 of aluminum would suffice for a manned Mars mission (Haffner, 316). This statement would then also imply that this amount of shielding would also be adequate for a Lunar mission. This amount was deemed low by the SD&I team and through an iterative research and mass trade-off process a figure of 10 gm/cm^2 shielding was agreed upon for normal radiation protection.

The occurence of a radiation storm of high intensity while the vehicle is deployed could prove lethal to the crew. It will be assumed by the time of deployment of this vehicle on the surface of the moon that an early warning system will have been developed and would be at the disposal of the crew. One of the concerns addressed during the conceptual design of the vehicle was that of providing the crew with sufficient shielding during the occurence of radiation storms and solar flares.

3.4 Airlock

In order to satisfy our mission requirements, an airlock would be necessary for the lunar rover. The function of an airlock is to allow the crew and equipment to enter or exit the vehicle without depressurizing the whole craft. A conventional airlock design will be used.

3.5 Vehicle Shell

The cylindrical shape of the main vehicle requires less wall thickness than our original box-shaped vessel to maintain the same internal pressure. The internal shell will be made of 2219 aluminum alloy. Aluminum is a proven material for lining pressurized vessels due to its weight-to-strength ratio (0.5) and its manufacturing capability. It is easily maintained and is suited for welding and forming. The internal framing will be welded together.

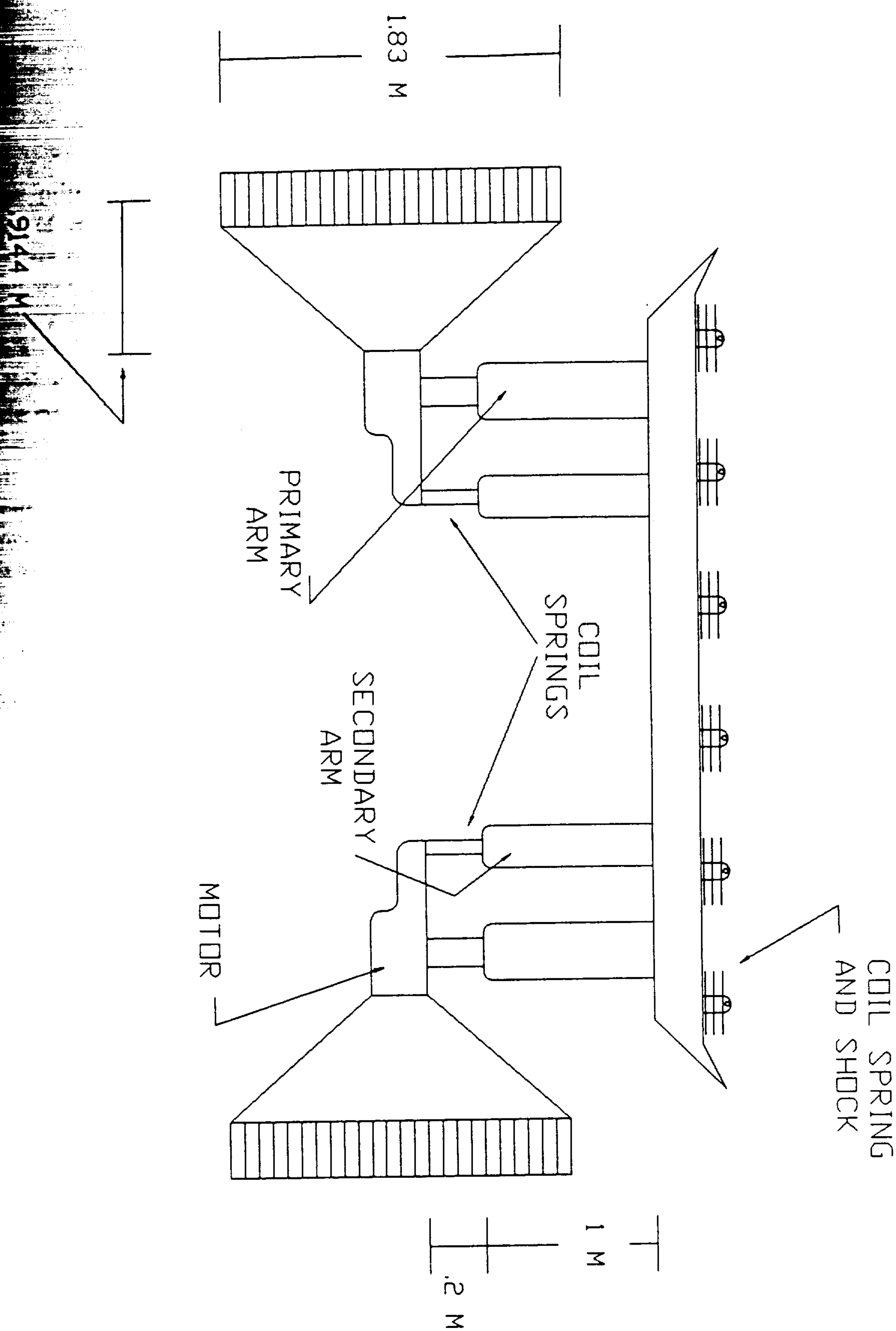

Figure 3.1. Primary and secondary suspension.

4. AVIONICS

The primary purpose of the avionics system is to successfully integrate a comprehensive set of general aviation avionics functions into a more complex system architecture to meet users needs by improving the safety and dependability of the vehicle system operations without increasing the required astronaunts training/experience by over exploiting advanced technology in computers, displays, and overall system design. The overall purpose will be to design a system at an affordable price. The system will be comprised of Avionics Vehicle Control, Robotic Arms/Video, Navigation, Communications and Data Transfer/Acquisition to provide critical information, improved functional capability, shared electronic displays without losing important considerations about overall system cost, reliability, producibility, and overall maintainability of the entire avionics system. The mass of the total avionics system is about 100 kg ± 5kg, and the volume of the avionics system is 4.5 m^3 which includes the avionics display of 0.5 m^3, communication system of 1 m^3 and workstation of 3 m^3. The total power requirement of the avionics system is approximately 600 watts.

4.1 Workstation

The concept for a workstation is envisioned as a modular, reconfigurable, expandable, general purpose, human engineered workstation for use by scientists, technologists, design and system engineers and space and ground operators. The workstation encompasses concepts of machine independence, modularity, standardized interfaces, expert system technology, and human machine interaction techniques.

4.2 Input and Output Devices

The primary input device of the workstation is the keyboard which will be attached to the workstation or will be remote, so astronauts can enter data directly in memory without coming near the workstation. There will be other devices available for input such as touch sensitive screen, optical character reader or light pen. There will be a digital mouse, or track ball to enhance the capabilities of the workstation.

4.3 Communication

Regarding communication requirements, the vehicle should be able to communicate to the base and receive from the base. According to our mission requirement, the vehicle will have the range of about 1000 km. The vehicle should remain visible to the base. For distances greater than several kilometers, a tower antenna would be needed at the base, the vehicle, or both.

One or more lunar orbiting satellites would also allow communication between a vehicle and the base. Use of one low lunar orbit satellite would limit communication periods to those when the satellite is visible to both the base and the vehicle. Continuous communication would require that several low lunar orbit satellites be spaced appropriately in lunar orbit. See Fig. 4.1 for details.

4.4 Link Performances and Antenna Types

Link-performance analysis deals with sizing communication system power and antennas so that the received signals are strong enough that the data to be sent can be extracted from the signal.

There are enormous numbers of antenna types, corresponding to a wide range of gains and bandwidths. Of all of the antennas available, the dish reflector possesses a major advantage because it concentrates signal energy on the receiver and thus improves the signal-to-noise ratio.

4.5 Navigation

Navigation for a vehicle on the moon is difficult because the moon does not have a specific coordinate system as we have on earth with respect to North and South pole. The navigation system is divided into the following main displays:

- Attitude Indicator - Provides indications of vehicle's pitch and roll. This instrument indicates PITCH upslope (u) and downslope (d) within a range of $\pm 25°$. The damper on the side of the indicator can be used to damp out oscillations.

- Heading Indicator - displays the vehicle heading with respect to lunar north.

- Bearing Indicator - shows the bearing to the base.

- Distance Indicator - reports distance traveled by the vehicle in increments of 1 km.

- Sun Shadow Device - determines the vehicle's position whith respect to the sun. This heading can be compared with the gyro heading at regular intervals as a check against gyro drift.

- Speed Indicator - shows the vehicle velocity from 0 to 20 km/hr, and is driven by odometer pulses from the right rear wheels.

- Gyro Torquing Switch - adjusts the navigation gyro to correct the HEADING indication during navigation update.

- Distance Indicator - shows the distance to the base.

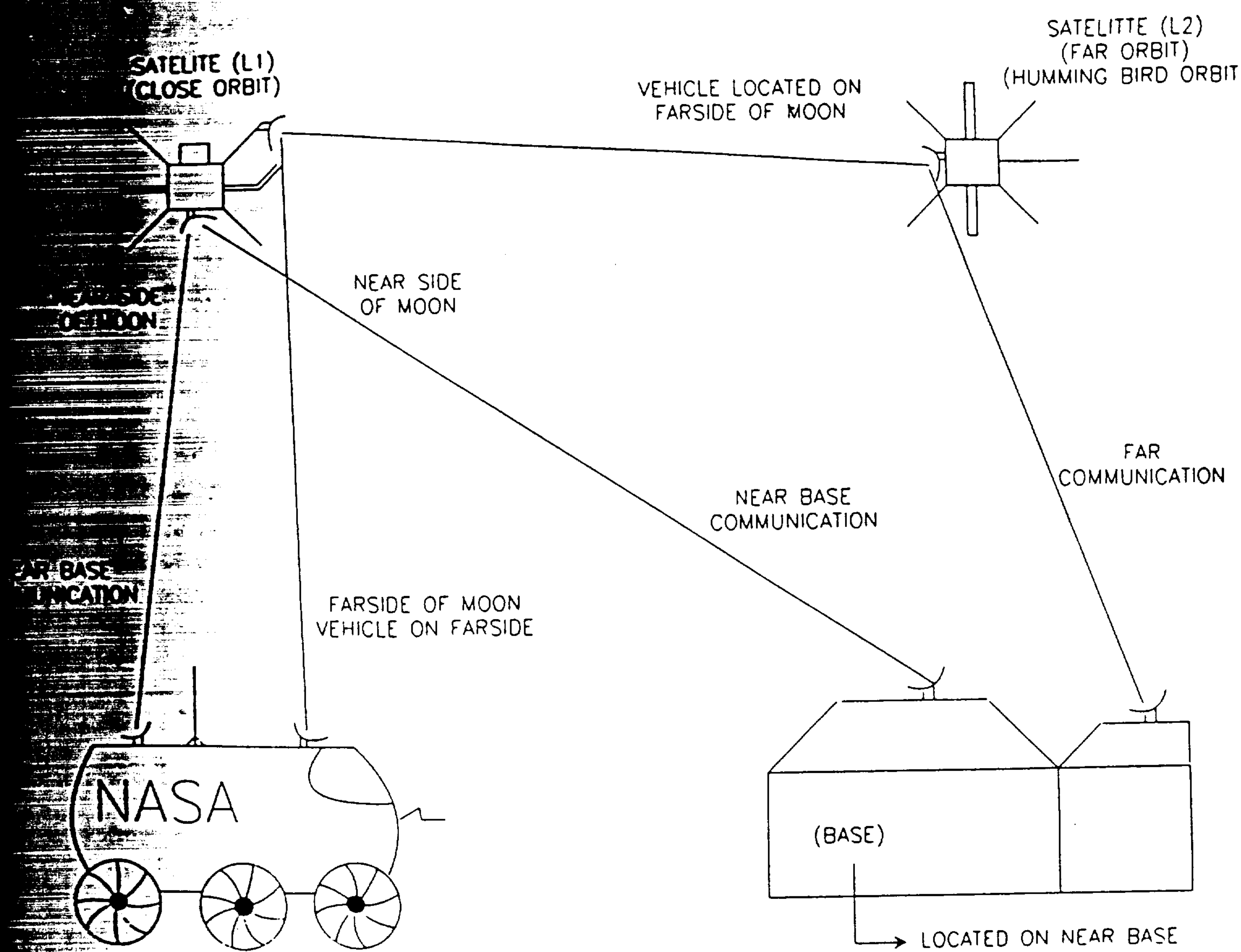

Figure 4.1. Communication network.

4.6 Heads Up Display

The heads up display will provide the pilot with critical information about human aspects, robotic arm, and the pathfinder. A helmet-mounted visual display system provides an astronaut with a broad range of visual information for experiments. The helmet-mounted display offers a nearly unlimited field of vision.

4.7 Robotic Arms

The design of the robotic arm will incorporate key issues of compactness, versatility, reliability, accuracy, and weight. The arm can be used on both the lunar vehicle and lunar base for a variety of functions. The lunar vehicle will have two connections for the robotic arm; they are to be located on the lower center front and rear of vehicle.

4.8 Electronically Scanned Laser Pathfinder

The Electronic Laser Scanner will be a device used on the Lunar Rover to sweep across its field of view without any mechanical moving parts by means of laser diode array(s) and charge-coulped cameras (CCD), which will measure the distance to objects between 0.5 and 20 meters away. The scanner device will guide the Lunar Rover vehicle around large to medium scale obstacles.

4.9 Moving Map Display Processor for finding LC Path

A VLSI circuit design implements a processor to find the lowest-cost map path by associating a traversal cost at each pixel node and calculating at each node the total cost of a path from a unique originator node to that node. This design concept will be very important in the Lunar Rover due to the mission requirement of a distance of 1000 km roundtrip.

5. THERMAL/FLUID

5.1 Environmental Requirements

The space environment that will be experienced on the Lunar surface poses many problems to the engineer, one of which is the support of life aboard the vehicle. Because of the closed nature of the system the ability to revitalize the atmosphere becomes a major undertaking as thus as controlling the proper parameters necessary to maintain good health for the astronauts. Several important conditions are temperature, pressure, humidity, composition, and purity. The biological needs of the astronauts must be quantified and the effects of certain conditions evaluated to ascertain their hazard levels.

5.2 Waste Removal and Storage

Storage will consist of a cylindrical tank of thin stainless steel sheet with an insulation jacket to reduce heat dissipation. The waste will be treated chemically with active enzymes which break down the bacteria growth and reduce odors. The urinal system will be sealed when not in use to reduce accumulation of odors in the latrine. A forced air system will complement the toilet to ensure proper direction of waste material. The chemical treatment system will be controlled by a flow meter which can sense additions to the tank. The chemical treatment will consist of sulfuric acid (10(a triple salt monopersulfate compound) which will disinfect, control pH to between 2.0-2.5 and fix free ammonia and ammoniated compounds.

5.3 Water Supply

The water will be stored in cylindrical tanks to minimize space requirements. Storage will be external to allow for modularity and maintenance. A pump will provide usable pressure for tasks such as showering, waste removal and galley feedwater. The estimated power consumption is 391 W at a flow of 0.456 m^3/hr. See Fig. 5.1 for details.

5.4 Cryogenic Storage

The atmosphere in the vehicle will be composed of a mixture of 80% nitrogen and 20% oxygen, which is very close to the 78.084% nitrogen, 20.9476% oxygen, plus traces of other gases for normal atmospheric breathable air. This will be accomplished through the supply of oxygen and nitrogen in two separate cryogenic cylindrical storage tanks located outside the vehicle and mixed accordingly (cryogenic storage tanks are usually of the spherical form, but due to space restraints and requirements cylinders will be implemented).

The important concern of safety in the cryogenic fluid storage vessels is addressed in three separate ways, being;

- 1. The inner-vessel pressure-relief valve

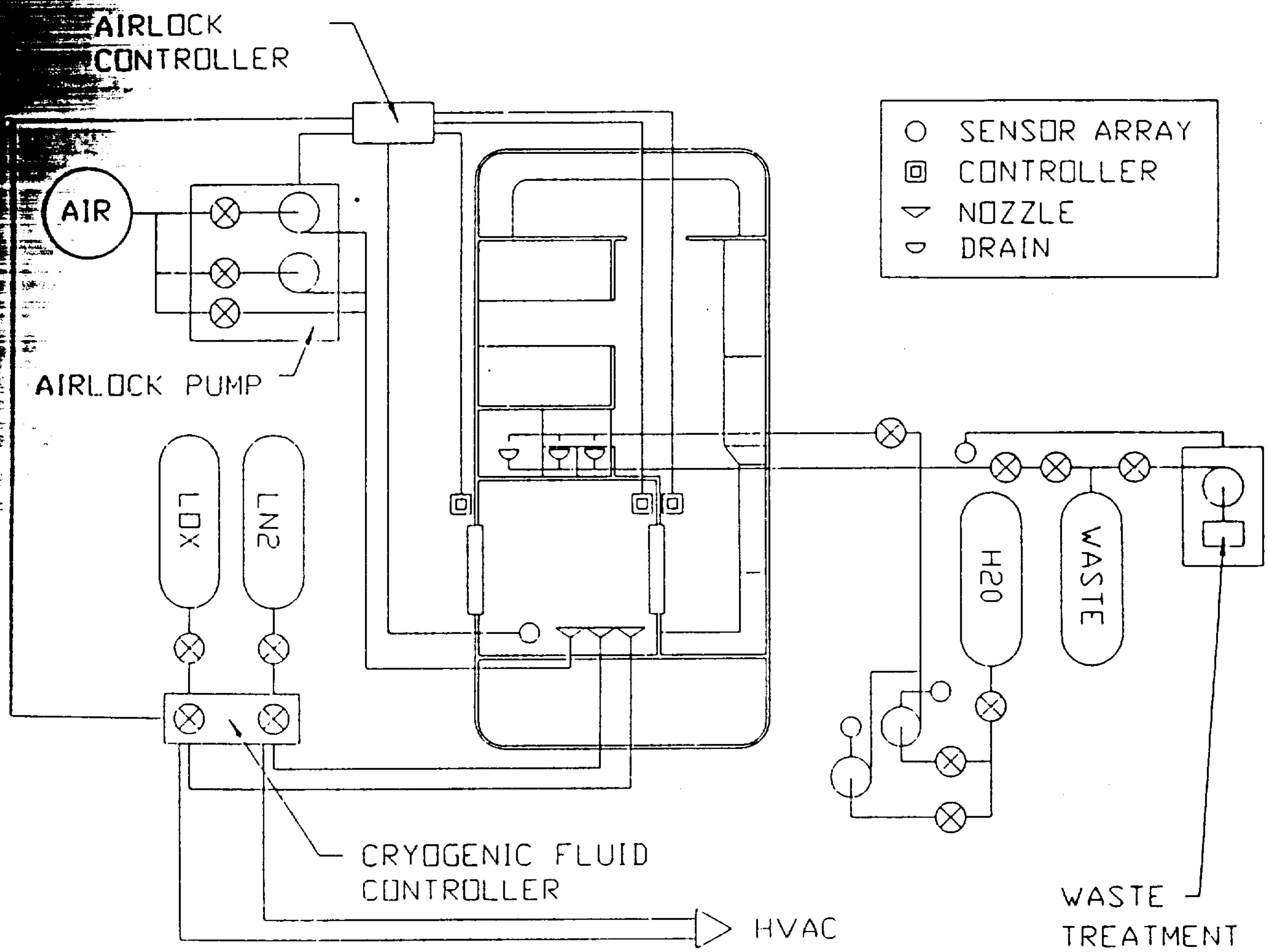

Figure 5.1. Water supply and waste removal schematic.

2. The inner-shell burst-disk assembly

3. The annular-space burst-disk assembly

Leak Containment

The issue of leak containment in the vehicle is of high importance. Because of the high vacuum which characterizes the lunar environment, maintenance of a suitable atmosphere in the vehicle is imperative. It was determined that the responses of the crew would be most favorable if the internal pressure of the vehicle would be close to the pressure on earth. The pressure chosen for the cabin is approximately 12 psi, compared to 14.7 psi at sea level on earth. With regard to the structure of the vehicle, the inside living quarters cabin shell will be surrounded by another shell to provide a deterrent to leak propagation.

5.6 Airlock Management

The airlock is the only outlet from the vehicle for the astronauts while on a mission. The airlock has the important function of being the last protection the astronauts have from any physiological problems which might result from the pressure decrease which occurs during EVA. For this lunar rover, the plan is to maintain the internal cabin pressure at 12.0 psi.

A compressor will be used to depressurize the airlock. A second compressor will be carried in the vehicle as a redundant measure. The compressors will require no more than 15 kW of power during airlock pumpdown. The first stage of depressurization will require 7.2 kW and the second stage requires 14.9 kW of power.

5.7 Fire Suppression

The hazard of fire aboard the vehicle is compounded by the closed loop system and the restrictions it places on the emergency equipment. There are many ways to combat a fire, all use the same basic principle which is removal of oxygen from the flame. The two methods consist of removing the oxygen by removing all air and replacing all available oxygen with inert materials (CO_2, Halon, dry chemical). These two methods will be emplemented through the use of CO_2 in the cabin areas and Halon 1301 in the electrical compartments.

6. POWER GENERATION

6.1 Radioisotope Generators

To meet our critical power requirements, a dynamic isotope power system has been selected. The isotope used in the system is Pu^{238} - one of a group of reactor produced fuels including Cm^{242} and Cm^{244}. It should be noted that reactor produced fuels can be divided into two classes: those that absorb one neutron and those that absorb more than one neutron. In the first class, a stable isotope captures one neutron and thus becomes radioactive. In the second class, a stable isotope (one with a long half-life) absorbs more than one neutron until it ends up as the desired radioisotope. Pu^{238} is characteristic of the second class of fuels.

6.2 Fuel Capsules

Metallic fuel capsules that contain long-lived alpha emitters must contain a vent for the helium gas generated by the radioactive decay of the nuclear fuel - unless adequate space is provided within the system for such venting to occur. These vents can be either selective or nonselective. Selective vents pass helium, but retain any larger gas molecules and solid particulates from the fuel. Nonselective vents also retain solid particulates from the fuel, but pass helium and other gaseous effluents, including uncondensed fuel, impurity vapors and possibly other fuel decay products such as radon.

6.3 Overall Design

The overall design of the DIPS power system consists of five major components - (1) an isotope heat source, (2) a compressor, (3) a thermal radiator, (4) a turbine, and, (5) a generator. The components have been integrated so that the complete system follows a closed Brayton cycle configuration. Based on this configuration, heat addition and rejection occur at constant pressure, while expansion and compression are assumed to occur at constant entropy. To simplify the design of the power system, it was organized so that both the compressor and the turbine make use of the same shaft.

6.3.1 Radiator Design

The design of the radiator for the lunar rover will follow a configuration involving a series of tubes through which the coolant will flow. The mass flow rate of the coolant (helium) was found to be 0.0904 kg/s and the specific heat, C_p, was determined to be a constant value of 5.193 KJ/Kmol·K.

Considerations

ent that increased power requirements would become necessary, it should be ynamic power conversion units can be coupled with radioisotope heat sources. that the power generation range is extended beyond that practically obtainable ystems (such as telluride TE converter systems), and lower unit costs are obtained gher power conversion efficiencies. A bar chart of the power requirements can be 6.1.

ckup Power

maximum power required for the Lunar Rover while traversing a 20° slope is 43.4 The maximum power requirement for static operation, which includes experimentation, kW$_e$. The maximum power required if all of the systems are working simultaneously are at maximum operating conditions is 53.9 kW$_e$.

6.6 Propulsion System

The propulsion system for the lunar rover consists of electric motors designed to meet the following requirements: variable torque, variable speed, light weight, high efficiency, high torque for obstacle clearance combined with optimum speed to maximize the vehicle's exploration range.

6.6.1 Motor

The brushless DC motor basically contains the following main components: (1) motor, (2) sensing system, (3) electronic commutator and control. The brushless motor consists of a rotor on which permanent magnets are mounted. These magnets are always arranged in pole pairs. The winding is placed in an external, slotted stator.

6.6.2 Power Control Methods

The method of power control to be used in this system will include a varying supply voltage to the commutation system. The six switching transistors will control commutation at the proper angular intervals and the series connected power transistors will handle velocity and current control of the brushless motor. This can be accomplished by pulse-width or pulse-frequency modulation.

6.6.3 Tachometers

Tachometers are often necessary in high-performance servo applications, where they provide velocity feedback for speed control purposes or servo system stability. For this system,

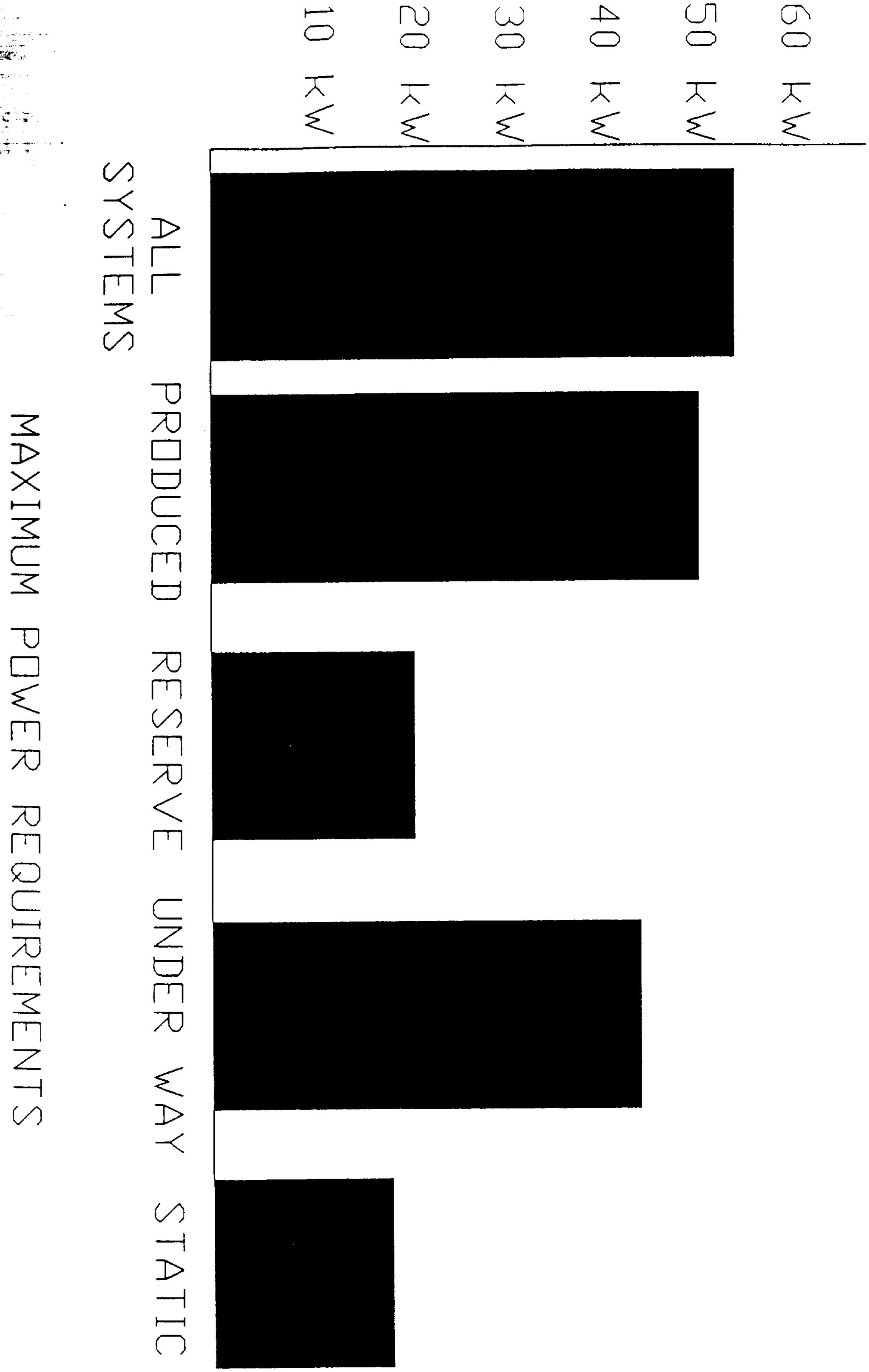

Figure 6.1. Power requirements for lunar rover.

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...ro-Craft** brushless DC tachometer will be used. This tachometer is based on a per-
...**magnet** motor and a multi-coil stator structure, which is commutated by an MSI

[illegible]pact of NASA/USRA on University, Faculty & Students

[illegible] a joint college, so the benefits of participation in the Advanced Design [illegible] come to both universities. The faculty of the college expect that the general [illegible] the Universities and College will continue to come from involvement in real-world [illegible] projects, support of new initiatives in engineering design education, recruitment of [illegible] engineering students, and participation with students from other universities in the [illegible] summer conferences.

[illegible]cipation by our faculty in the Advanced Design Program will come, as it has in the [illegible] from teaching design courses and supervising design projects that are established as a [illegible] of support from the Advanced Design Program. Specific benefits include involvement of [illegible]lty members in current NASA projects, personal interactions with NASA Center contacts, [illegible] opportunities for interdisciplinary teaching and research.

The major benefit to our students will come from working as project team members on [illegible]-world, system-level, open-ended, interdisciplinary design problems. These are the kinds of problems they will work on after graduation. Our claim for this benefit is supported by the experience of our graduates.

Looking to the future, this year's class, which has begun interviewing for jobs, reports substantial interest among employers in the student's experience in out Advanced Design Program supported system design project. We think this approach to teaching engineering design works, and we will continue it.